Integrating Crop and Fertilization Management Strategies for Soybean in the Central Pampas

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A field study in the central Pampas of Argentina evaluated the relative impact of more intensively managed crop and fertilizer practices on soybean growth and yield.

The main objectives of sustainable intensification in agriculture are increased crop production, maximized resource use efficiency, and a reduction in negative environmental impacts within agro-ecosystems. To achieve each of these objectives, it is best to understand the many processes that affect crop production (e.g., the potential for biomass production, its partitioning to reproductive plant parts, the efficient use of resources [water, light, nutrients]), as well as the magnitude of the yield gap that exists from using current production practices rather than those recommended for more efficient use of resources and inputs.

The potential yield (PY) of soybeans is determined genetically, but it is difficult to estimate PY precisely in the field, even assuming no water and nutrient constraints or yield-limiting factors (insects, weeds, diseases). The concept of maximum attainable yield (MY) is more practical. MY will vary depending on the site's growing conditions and crop management. Under rain-fed conditions, where water is the most limiting factor, MY can be defined as MY_d (i.e., maximum attainable yield under dryland conditions). Combinations of row spacing, planting date, plant population or genotype contribute to narrow the gap between common practice and that recommended for high yields. Recent studies in Argentina have shown that various management practices increase soybean production, e.g., reduction of

Changes to specific crop management practices increased both biomass and seed yield. Seed yield improvements were mostly achieved through greater production of biomass and number of seeds. These effects were further enhanced under more intensive fertilizer management. Processes occurring at seed set (R2 to R5) and pod filling period (R5 to R7) were the most affected. Optimizing the growing conditions within these stages is critical when looking for higher yields. Increased yields under more intensive strategies were associated with higher uptake of N, P, and S.

KEYWORDS:
intensification; biomass; leaf area index; nutrient uptake.

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; S = sulfur; B =boron; Zn = zinc; HI = harvest index.

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Table 1. Description of crop and fertilization management strategies studied during the 2014-2015 and 2015-16 seasons.

Treatments		Farm practice (FP)	Fertilizer intensification (FI)	Management intensification (MI)	Management + fertilization intensification (MFI)
		Crop Management Strategies			
Target population, pl/ha		290,000 (331,731)*	290,000 (320,513)	440,000 (413,462)	440,000 (431,090)
Row spacing, cm		52	52	26	26
Cultivar		DM 4970	DM 4970	LDC 4.7	LDC 4.7
Planting date	2014-15	28 Nov	28 Nov	7 Nov	7 Nov
	2015-16	18 Nov	18 Nov	5 Nov	5 Nov
		Fertilizer Management Strategies			
Inoculation		No	Yes	No	Yes
P		No	20 kg P/ha**	No	20 kg P/ha**
S		No	20 kg S/ha**	No	20 kg S/ha**
Micronutrients (R2 to R3)		No	Foliar B	No	Foliar B
N applied at R5		No	50 kg N/ha***	No	50 kg N/ha***

*Numbers in parentheses indicate the achieved population. **Surface-broadcasted in July. ***Surface-broadcasted.

row spacing (Rizzo et al., 2009; Bacigaluppo et al., 2011; Martignone et al., 2011), correct choice of genotype (Bacigaluppo et al., 2013), or early planting (Mercau et al., 2004; Enrico et al., 2013). So to reduce existing yield gaps it is necessary to know and apply best management practices. Soils may contain insufficient nutrients to support high yields and these deficits must be corrected in order to approach MY_d. These deficiencies are specific to each field and can be characterized with soil and tissue analysis. In the Pampas region of Argentina, limitations of N, P, S, or micronutrients such as Zn have all been identified (Salvagiotti et al., 2012; 2013; 2017; Barbieri et al., 2017).

It is generally accepted that it is difficult to consistently get further yield increases every year if the gap between actual and attainable yield is < 20%, or within 80% of MY_d. Soybean yields in Argentina have been increasing by 1.3% annually (30 kg/ha/yr) since 1990-91. But recent research suggests the current national gap between actual and MY_d is 32%, which leaves room for improvement (Merlos et al., 2015). Two experiments were planted in the 2014-2015 and 2015-16 seasons in Oliveros, Santa Fe, Argentina with the objective of evaluating the impact of crop and fertilization management strategies on MY under rain-fed conditions.

Study Description

Four treatments evaluated combinations of two fertilization and two crop management strategies (**Table 1**). Farm practice (FP) and fertilizer intensification (FI) were characterized by more conservative crop management decisions (i.e., use of a cultivar common to the area in recent years, planted in mid to late November with a row spacing of 52 cm). The more intensive crop management treatments (MI and MFI) tested narrower (26 cm) row spacing, a cultivar with higher yield potential, and planting in early November.

In FI and MFI, soybean was inoculated, and plots were fertilized with P and S by broadcasting in winter according to National Institute of Agricultural Technology (INTA) recommendations. Foliar B was applied during the R2 stage (Fehr and Caviness, 1977), and N was surface applied at R5. In contrast, MI and FP did not receive fertilization or inoculation. All treatments were organized in a randomized complete block design with three replications.

Aboveground biomass (expressed as dry matter, DM), and leaf area index (LAI; data not shown) were determined in the stages R2, R5, and R7. Grain yield (13% moisture), number of seeds, individual seed weight, number of fertile nodes located on the main stem, and seeds per fertile node were determined.

Watch video about this study

At R7, aboveground organs (leaves, stems, podwalls, and seeds) were sampled and analyzed for N, P, S, B, and Zn to estimate nutrient uptake. Harvest index (HI) for each nutrient was calculated as the ratio of nutrient in the seed to total nutrient uptake.

Weather and Soil Conditions

In the 2014-15 season, rainfall during the crop cycle (emergence to R7) was 633 and 574 mm for the early (MI and MFI) and late (FP and FI) planting treatments, respectively. These values were 40% and 25% higher than normal according to the historical record (1971 to 2014) for early and late sowing, respectively. Precipitation exceeded potential evapotranspiration (PET) for both management practices. In the 2015-16 season, rainfall during the crop cycle was 719 and 697 mm for the early and late-sowing treatments, respectively, which were 43% higher than the historical values.

During the period of seed growth (R1 to R5), precipitation exceeded PET in 2014-15, but fell short in 2015-16. During the period of seed filling (R5 to R7), precipitation exceeded PET in both seasons. Soil analysis showed values of typically degraded soils in the southern area of Santa Fe. Organic matter was around 2% and pH was 5.3 and 5.2 for the 2014-15 and 2015-16 seasons, respectively. On the other hand, Bray P-1 concentration was high in 2014-15 (29 ppm) and closer to the critical threshold (15 ppm) for 2015-16.

Crop Growth

Early in the season at R2, DM production was 49% higher than FP in the treatments that had more intensive crop management (MI and MFI). However at the beginning of seed filling (R5), DM production was similar across treatments. A trend towards higher DM production was noted for treatments that included the more intensive fertilizer management strategy (**Figure 1**). The MI and MFI treatments had aboveground biomass production greater than 10,000 kg/ha at physiological maturity, exceeding FP and FI by 24%. The second year of study showed larger differences between treatments than the first year.

Seed Yield

Differences in early season precipitation during seed growth (R1 to R5) caused seed yields to be 26% higher (+1,100 kg/ha) in 2014-15 than in 2015-16 (**Table 2**). Since there was no year (Y) x treatment (T) interaction (i.e., treatment effects were similar between years), the effects of each treatment could be analyzed by examining specific treatment contrasts. This analysis found no yield benefit across years for either FI or MI over FP, but MFI did outyield FP by 8% or 360 kg/ha. Similarly, a comparison of FI + MFI vs. MI + FP (i.e., sum of treatments with intensive fertilization vs. treatments without intensive fertilization), determined that yields were 5% (220 kg/ha) higher if the intensive fertilization strategy was included.

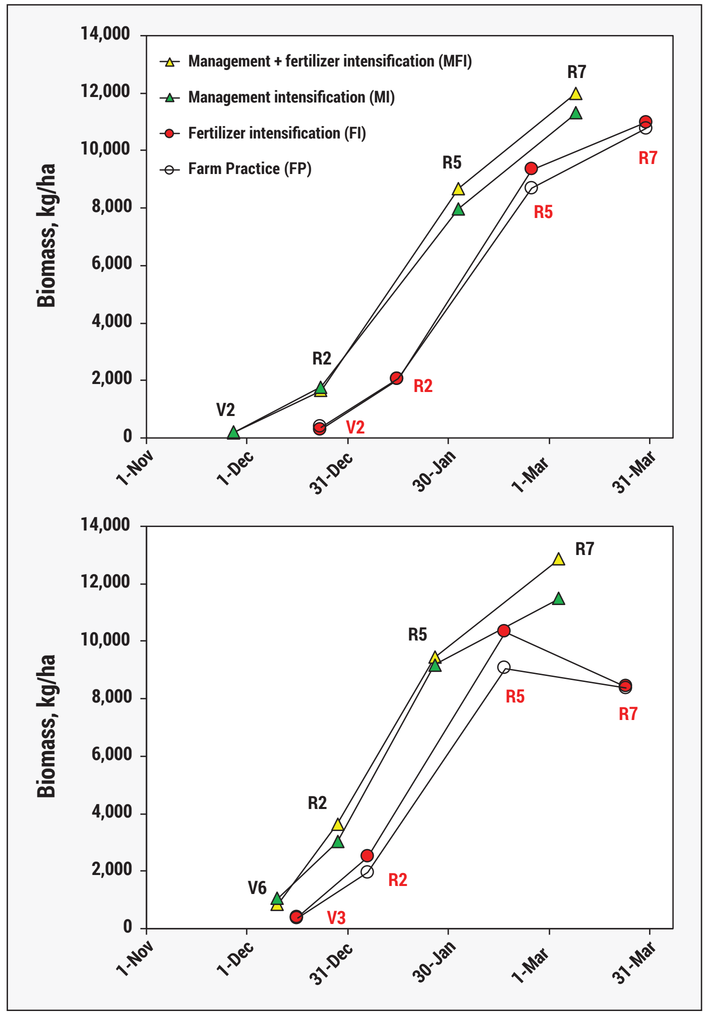

Figure 1. Aboveground dry matter accumulation for the different soybean production strategies in the 2014-15 season (top) and 2015-16 (bottom).

Table 2. Yield, seed number, and number of fertile main stem nodes for the different soybean production strategies.

Treatment*	Seed yield, kg/ha		Seed number/m²		Fertile main stem nodes/m²
	2014	2015	2014	2015	Average 2014-2015
FP	5,200	4,060	2,880	2,520	420
FI	5,490	4,190	2,880	2,600	400
MI	5,250	4,260	3,210	2,550	520
MFI	5,500	4,490	3,320	2,605	550
Year (Y)	0.01		< 0.01		0.14
Treatment (T)	0.19		0.05		< 0.01
Y x T	0.75		0.08		0.20
Treatment contrasts					
FI vs. FP	0.21		0.67		0.63
MI vs. FP	0.45		0.07		0.02
MFI vs. FP	0.04		< 0.01		< 0.01

*FP = current farm practice; FI = fertilizer intensification; MI = management intensification; MFI = management + fertilizer intensification.

Treatments including management intensification (MI and MFI) produced more (+32%) fertile nodes per m². This was related to the higher populations (+36%) achieved with the narrower row spacing. Although the number of pods per reproductive node was 18% higher for the FP and FI treatments, this effect was not enough to compensate for the lower plant populations and lower numbers of fertile nodes per plant. The increased number of fertile nodes resulted in a significant (13%) increase in seed number for MI and MFI over FP in 2014-15 only.

Seed set efficiency, a trait representing how much reproductive biomass is invested in producing seeds, showed values that were 71% higher in MI and MFI than in FP or FI (data not shown). Thus early planting and narrower row spacing provided a better growing environment for transforming accumulated biomass into seed. Considering that all treatments reached the same biomass at R5 (**Figure 1**), and the larger num-

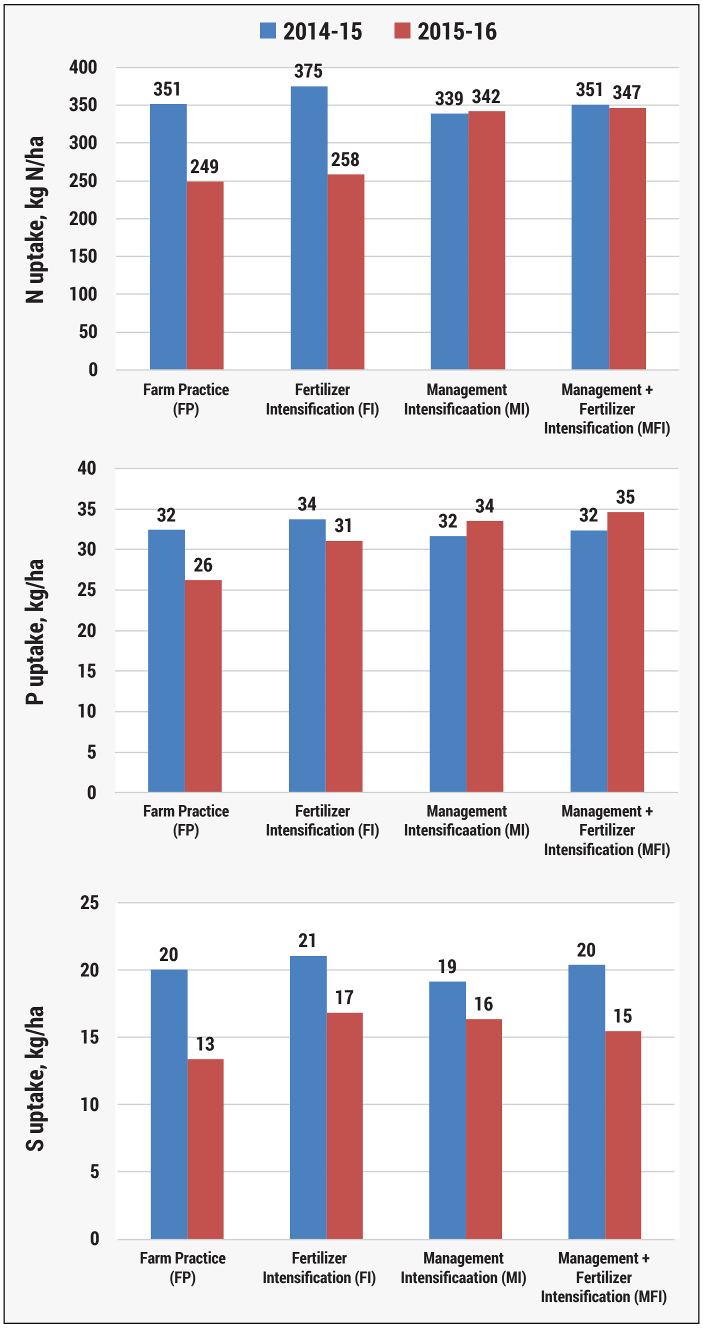

Figure 2. Total N, P, and S uptake for treatments testing different soybean production strategies in the 2014-15 and 2015-16.

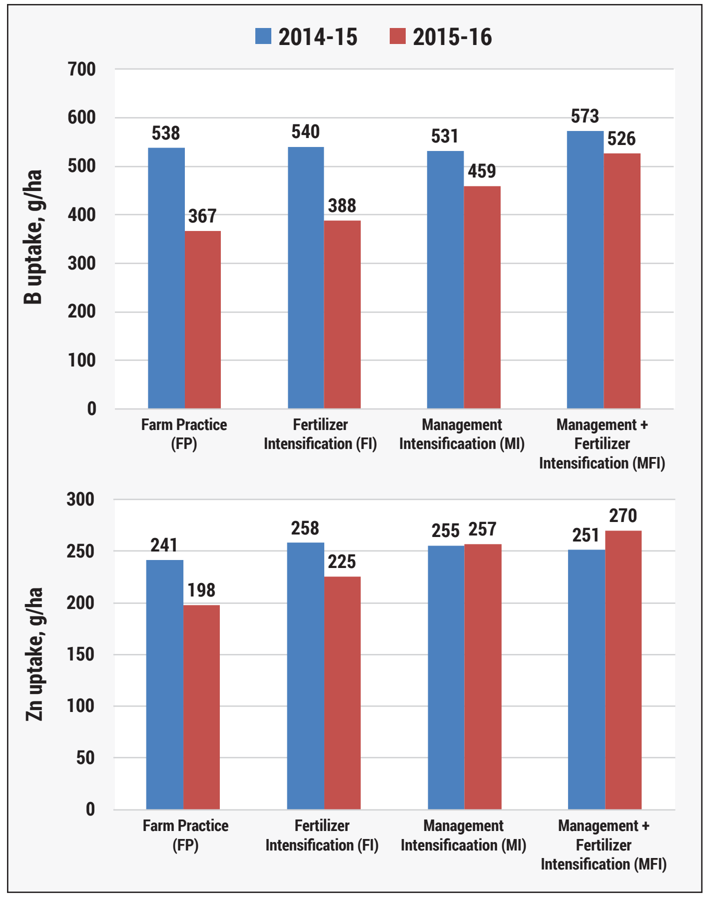

Figure 3. Total uptake of Zn and B for treatments testing different soybean production strategies in the 2014-15 and 2015-16.

ber of seeds produced in the MI and MFI treatments (**Table 2**), we suggest that the growing conditions between R5 and R7 are crucial for high soybean yields. Following this rationale, soybean yields might be improved by using genotypes that have longer duration R5 to R7 periods. However, these crops would need to extend their growth into conditions of declining radiation and temperature, which would likely be counterproductive. Also, early maturing soybean crops allow for early planting of cover crops, which are now being introduced in the Pampas due to their contributions to improved soil health and weed control.

Nutrient Uptake

For N, the average uptake across both seasons was 330 kg N/ha. No differences in N uptake were found between treatments in 2014-15, but MI and MFI had 36% higher N uptake than FP and FI in 2015-16 (**Figure 2, top**). This seasonal response was associated with differences in biomass production. Nitrogen harvest index, an indicator of how efficiently plants convert absorbed N into grain, was 25% higher in the treatments with more conservative crop management strategies (0.75 for FP and FI; 0.60 for MI and MFI). Average P uptake by soybean was 32 kg P/ha. MI and MFI had 7% higher P uptake than FP and FI (**Figure 2, middle**). Phosphorus harvest index was 11% higher for FP and FI (0.75) compared to MI and MFI (0.67). Average S uptake was 18 kg S/ha, and treatments failed to influence S uptake in either year (**Figure 2, bottom**). As with N and P, sulfur harvest index was higher (10%) for FP and FI (0.69) compared to MI and MFI (0.63). The average ratio for total N: P: S uptake was 18.4: 1.8: 1.

Average B uptake was 491 g B/ha. The MFI treatment had 11% higher B uptake compared to FP (**Figure 3, top**). HI_B was significantly higher in FP and FI (0.44) compared to MI and MFI (0.37). Average Zn uptake was 245 g Zn/ha, 15% higher in MI and MFI compared to FP (**Figure 3, bottom**). Zinc harvest index was not affected by treatment, but varied between 0.65 for FP and FI and 0.61 for MI and MFI.

Averaged across seasons, the higher yields obtained under intensification were associated with higher N (+16%), P (+14%), and S (+7%) uptake. But this increase in nutrient uptake can be mainly associated with higher biomass production since HI decreased for all three nutrients. Nutrient uptake responses to intensification also differed between seasons (i.e., N uptake was similar for FP and MFI in 2014-15 but MFI was 39% higher in 2015-16). The continuation of this study over additional seasons will provide better insight on this issue of variability.

Conclusions

These preliminary results show that more intensive soybean management practices increased biomass and seed yield in the central Pampas, mostly by affecting the number of seeds/m^2. Additional incorporation of more intensive fertilization practices magnified these responses. The growth and development that occurs at seed set and seed-filling stages is most affected by the intensification of crop management and fertilizer. Favorable growing conditions during these two critical crop stages contributes much to soybean yield.

Improved yields under crop and nutrient management intensification did result in variable increases in nutrient uptake in both seasons. Increased nutrient uptake was mainly related to increased biomass production. A follow-up to this study from work conducted in the 2016-17 and 2017-18 seasons will contribute further to this discussion on the relationship between seed yield and nutrient uptake under intensified soybean systems. **BC**

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